Paper ID #24660

WIP: How Students Externalize Epistemologies: Describing How Students Explain, Ground, and Consciously Construct Their Definitions of Engineering and Biomedical Engineering

Dr. Cristi L. Bell-Huff, Georgia Institute of Technology

Cristi L. Bell-Huff, PhD is a Lecturer in the Wallace H. Coulter Department of Biomedical Engineering at Georgia Tech and Emory University where she is involved in teaching and engineering education innovation and research. In addition to her PhD in Chemical Engineering, she also has an MA in Educational Studies. She has industrial experience in pharmaceutical product and process development as well as teaching experience at the secondary and post-secondary levels.

Todd M. Fernandez, Georgia Institute of Technology

Todd is a lecturer in the Wallace H. Coulter Department of Biomedical Engineering at Georgia Institute of Technology. His research interests are about engineering students beliefs about knowledge and their formation through the engineering education experience.

Dr. Kali Lynn Morgan, Georgia Institute of Technology
Prof. Joseph M. LeDoux, Georgia Institute of Technology

Joe Le Doux is the Associate Chair for Undergraduate Learning and Experience in the Department of Biomedical Engineering at Georgia Tech and Emory University. Dr. Le Doux's research interests in engineering education focus on problem-solving, diagrammatic reasoning, and on the socio-cognitive aspects of the flipped and blended learning environments.

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Introduction

In this work in progress paper, we look at how biomedical engineering first-year students conceptualize engineering and how their conceptualization changes over the course of a one-semester introduction to biomedical engineering learning experience. The study is intended to engage in a deeper analysis of how students draw boundaries around what is and is not knowledge relevant to the engineering discipline – which we refer to as epistemological boundaries [1,2]. Epistemologies describe the nature and extent of knowledge – including notions of both the concept of knowing and what knowledge can be known [1,3]. In this study, we focus on the *extent* aspect wherein we use the term epistemological boundaries to refer to what information is and is not considered to be part of the engineering discipline's body of knowledge.

Studies suggest that students have a complex understanding of what engineering, and by extension engineering knowledge, is [4]. Dusmore et al. [4] show that students' perceive engineering leadership as grounded in technical competence when working with others. They also found that students see strong contrasts between the theoretically focused work of engineering school and the practically focused work of engineering jobs. Similar to Dusmore et al, Stevens et al [5] found that students perceive engineering work as the real world, meritocratic, and difficult. Critically, the noted findings about students' characterizations of engineering overlap with expert discussions of engineering work, but do not match exactly. Such expert discussions often describe engineering through its inclusion of different disciplinary perspectives on the boundaries of engineering knowledge (e.g., de Figueiredo [2]). Qualitative or judgmental descriptors of engineering culture (e.g., Dusmore et al [4]) are less common.

Having drawn these boundaries, which are external to the individual, an individual can then use them (e.g., adopt or reject portions or the whole) as part of the process by which they develop an individual identity as an engineer [6]. That identity can only exist through an individual's (i.e., student's) process of engagement, immersion, and assimilation into engineering [1]. While identity does have dimensions of process, such as engineering degree programs, that process relies on epistemological boundaries and the expressions of a cultural relationship via beliefs, practices, and language.

Our study adds to an ongoing thread within engineering education: Understanding students' conceptualization of engineering, engineering work, and engineering concepts. Work in engineering education seeks to align expert articulations of engineering knowledge with engineering education. That work appears in tension with students' differentiation of the highly theoretical world of engineering school from their more practical perception of engineering work [7,8]. These perceptions exist about things external to students and provide insight into students' epistemological boundaries – representing information about what the student counts as engineering knowledge [2]. Both individuals and groups of individuals hold beliefs about epistemological boundaries, and those boundaries interact.

In planning this study, we were especially interested in which disciplinary perspectives students majoring in biomedical engineering drew on in defining engineering. We see understanding students' perception of engineering as especially important in biomedical engineering because it is both heavily interdisciplinary and heavily human focused [9,10]. In biomedical engineering, content traditionally seen as mechanical, electrical, and chemical engineering is merged into novel curricula that are human-focused, creating conditions where biomedical engineering students may develop a different understanding than students from other engineering majors.

The purpose of this paper is a preliminary analysis of students' reflections on the epistemological boundaries of engineering. We want to understand the boundaries that students establish regarding engineering and the way in which they articulate those boundaries. As an initial step towards that goal, our work in progress research questions are: (1) At what level of reflection do first-year biomedical engineering undergraduates articulate a definition of engineering? And, (2) What areas of knowledge do biomedical engineering students include within their personal definitions of engineering?

Framework and codes

We used two theoretical frameworks in the study. The codes from both frameworks and the reference sheet used by coders are in the appendix.

The first, by Kember et al. [11], describes the levels of reflection in student work. Kember et al. identify four ordinal levels at which we might see students' articulation of an engineering epistemology: habitual action, understanding, reflection, and critical reflection. This framework aligns with the first research question by providing insight into the complexity with which students express their definitions of engineering. By looking at the levels of reflection, we gain insight into how students' do (or do not) connect the epistemological boundaries that they draw around engineering to their personal experiences.

The second framework, by de Figueiredo [2], describes engineering's epistemological boundaries (i.e., what knowledge is and, by extension, is not part of modern engineering work). In creating the framework, de Figueiredo summarizes work in engineering education on the disciplinary epistemologies that describes engineering as made up of four disciplinary perspectives - engineers as a sociologist, designer, doer, or scientist. The de Figueiredo framework aligns with the second research question and allows an analysis of what disciplinary knowledge students' definitions of engineering include.

Study design

Data and data collection

Data collection for the study occurred in an introductory biomedical engineering course at a large research university in the American south. The course is designed to introduce students to the biomedical engineering department, design thinking, reflection, and other associated topics. The students were taught in three sections, each of which followed identical course plans. To focus on developing students' reflective skills, the students completed nine reflective assignments with a focus on formative feedback as well as readings and in-class activities related to reflection.

For this study we analyze two reflection assignments from the first and 13th weeks of the course, the schedule of which is included in the appendix. The two assignments (shown in full in the appendix) both asked students to articulate individual definitions of both engineering and biomedical engineering. The second assignment asked students to reassess their initial definition and identify what had changed about it. In class, instructors graded both assignments using a specifications grading approach that relied on an explicitly identified set of 'success criteria.'

Population

We received both written reflections from most students enrolled in the course (n=56). A few students (4) did not complete the final reflection. The responding population consisted of first-year undergraduate biomedical engineering students enrolled in the department. We did not collect demographic data.

Analysis

The first three authors performed the analysis process. We began our analysis by reviewing both theoretical frameworks and then discussing them as a group. We then jointly generated practical definitions of those levels for coding. Student reflections could receive only one code for the level of reflection because of the hierarchical nature. Because the roles of an engineer were not considered to be mutually exclusive, coders could apply as many of the codes as were supported by the data to each reflection. Each coder applied codes for both the level of reflection and the roles before moving to the next student reflection. We normed our coding for the first several reflections, then continued to code on our own. We coded both pre- and post- reflections for each student separately, first coding the pre reflections and then coding the post reflections.

Results

For this WIP paper we are primarily reporting a quantitative summation of the coding process for our sample. However, we have included a few notes on our qualitative findings in the appendix that we found either particularly useful for highlighting certain code categories or which provided interesting insights into students' perception of the disciplinary bounds of engineering.

The first theoretical framework, based on coding the level of reflection of the student artifact described by Kember et al. [11], is summarized in both count form (Table 1) and percent form (Figure 1). For both the pre and the post reflective artifacts, the most commonly coded level of reflections was *reflection* representing about 50% of the artifacts in both the pre and post sample. In the pre sample, the second most common level from the Kember framework was understanding (21 participants, 37%). However, in the post sample the second most common categorization was critical reflection (18 participants, 32%). We suspect that shift is partially but not exclusively linked to the post reflective-prompt's language which specifically asked about change, a consideration we plan to address in future analysis.

Table 1 Count data from reflective level coding

Level	Pre	Post
Habitual action	3	0
Understanding	21	6
Reflection	29	28
Critical Reflection	4	18
Not submitted	0	5

We also assessed how students moved between the levels from the pre to the post reflection. That data is shown in Table 2. The most common result was that students identified as reflecting in the pre stayed at the reflection level in the post. The two most common changes were from understanding to reflection (10) and from understanding to critical reflection (8). These findings align with Kember et al.'s [11] observation that critical reflection requires engagement with and change of a perspective over time, making it inherently less frequent. The most common downward change was from critical reflection to reflection. In total, 28 students moved up the reflective scale while 6 moved down.

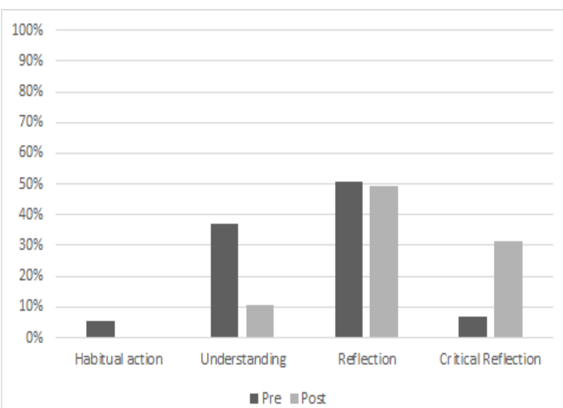

Figure 1 Percent comparison of reflection level in pre and post data

The results from using the de Figueiredo [2] framework to code the reflections appear in Tables 3 and 4 as well as Figure 2 on the next page. The most common disciplinary epistemology in both the pre and the post reflections was doer. The least common in the pre reflections was designer while the least common in the post was scientist. Overall, we identified an average of 2.3 (pre) and 2.1 (post) of the 4 epistemologies in the framework in each reflection.

Table 2 Comparison of levels of students' pre and post reflections

		Pre			
		H.A.	**U.**	**R.**	**C.R.**
Post	**Habitual action**	0	0	0	0
	Understanding	2	2	2	1
	Reflection	1	10	16	3
	Critical Reflection	0	8	7	0
	Not submitted	0	1	4	0

Future work and informal coding observations

Because this paper is a work in progress, we are eschewing a formal discussion of the results in favor of one focused on our future plans for this study and data set. In the title of this paper, we used the phrase "explain, ground, and consciously construct" to refer to students' epistemological beliefs about engineering. Our coding process provided insights into how previous literature is helpful and showed areas where our ongoing work needs to be informed by individual students' articulation of engineering.

Specifically, in future work we plan to build on a more inductive or grounded approach, because the coders found significant difficulty in coding students' language. For example, students' language did not directly align with de Figueiredo's. The students often used metaphors or examples when articulating those disciplinary boundaries; one example we plan to explore further is how students' use of the term 'design' changed throughout the semester. Yet, the coders saw, or inferred, intended meanings that do align well with the de Figueiredo framework suggesting there is value in deeper exploration of the boundaries that students draw. We are also interested in comparing definitions from students in different disciplines of engineering.

Table 3 Occurrence data of de Figueiredo codes

Discipline	Pre	Post
Sociologist	37	26
Scientist	24	17
Designer	17	37
Doer	54	42

Table 4 Number of de Figueiredo codes in a given reflection

Number	Pre	Post
1	7	5
2	30	30
3	15	12
4	5	5
Avg	***2.3***	***2.1***

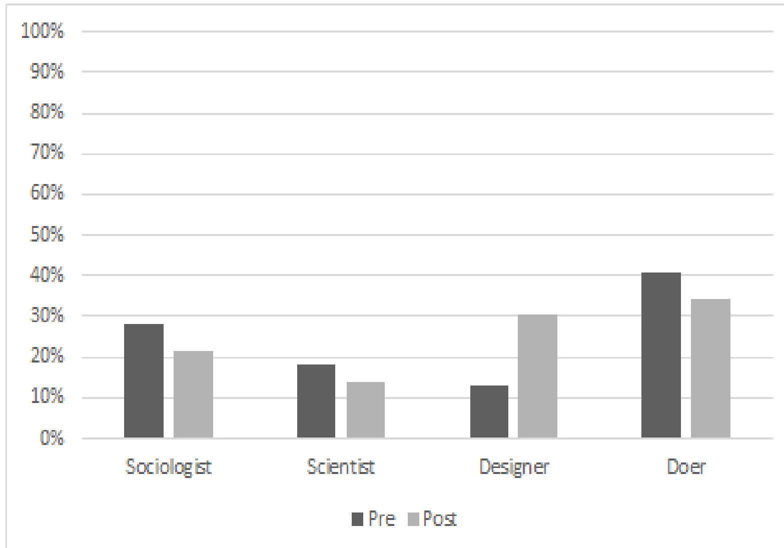

Figure 2 Percent comparison of de Figueiredo codes in pre and post data

Further, we note that the course (see schedule in appendix) included both instruction on reflection as well as instruction on design. Therefore, we are not particularly surprised to find that the most common increase in students' level of reflection was from understanding to reflection between the pre and post data respectively. In parallel, the increase in the design thinking code was also not surprising. In the ongoing analysis, we are very interested in a comparative analysis of the pre and post reflections that goes beyond our two sets of codes to specifically explore the influence of the course content. As noted in the methods, the course includes nine reflective assignments and the development of reflective capacity as an engineering skill is a core learning objective interwoven throughout the course. Similarly, the course also centered design thinking. We believe these two observations suggest that exploring how students' definitions of engineering change in relation to the course material is a useful area of future study.

Lastly, many students identified highly influential people or events that affected their definition. As an example, we identified two quotes that may indicate broader themes:

"I once had an opportunity to talk [to] a panel of women working as biomedical engineers at [company name], where they said they chose this career because of how they can directly see how their work is helping others."

"Based on lectures and speakers at my high school, engineering can be described most simply as the application of knowledge to solve practical problems."

These two quotes both highlight influences on students' definitions of engineering. Many students identified people as a source of information that had helped them build or change their definition. Examples included a parent, sibling or relative, working engineer, high school teachers, and even a YouTube channel. The coders noted that when students referenced working engineers, they tended to broaden definitions to include professional or teamwork skills. Conversely, students who were influenced by people who were not working engineers (e.g., high school instructors) tended to cite math, science, and practical problem solving in their definitions. Among several others, these influences and their relationship to students' definitions are something we plan to pursue further.

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Appendices

Course schedule

Class #	Topic	Assignments due
Class 1	Introduction to reflection What is 'BME'	N/A
Class 2	Intro to design thinking	Reflection - What is engineering Reading on four levels of reflection Preferred Name/Pronoun form Read and sign syllabus
Class 3	Shop introduction Project Presentations	Campus Map Design Project
Class 4	BMES introduction Interviewing skills Sense of belonging	Reflection - Working styles Design thinking reading
Class 5	Entrepreneurial mindset Seeing connections	Reflection - Design thinking Interview an upperclassmen
Class 6	Engineering storytelling	Reflection - Curiosity, Connections, and Value Research on dept.
Class 7	Entrepreneurial mindset 2 Design challenge	Reflection - Your unique BME contribution
Class 8	*Project work time*	Read DYL Introduction and Chapter 1 Podcast on undergraduate research
Class 9	Design project pitches BMED Landscape	Design challenge DUE (assigned week 7) Read DYL Chapter 2 Reflection - Workview, Lifeview, Integration Health/Work/Play/Love Dashboard
Class 10	Group reflect on GTJ Reflection as an eng. skill Mind mapping	Read DYL Chapter 3 Keep Good Time Journal
Class 11	Mind map sharing Creating an odyssey plan	DYL Chapter 4 + 5 DYL Mind mapping activity
Class 12	Intro to portfolio	Odyssey plans Portfolio reading
Class 13	Ritual design	Reflection - What is engineering ***Start work on your Portfolio*** Portfolio reading
Class 14	Present Odyssey plans Life prototyping	Reflection - Compiling your portfolio Submit portfolio Read DYL Chapter 6
Exam	Design exercise	

Reflective assignments

Note to readers: presented below is the entire assignment as given to the students. The success criteria represent the entirety of a specifications grading rubric that was used to assign a pass/fail grade to each assignment submitted by a student

1st assignment (pre)

Reflection Assignment: Week 1 - What is Engineering / Biomedical Engineering

General instructions:

One of our course goals is to give each student space to explore biomedical engineering, their plans at [INSTITUTION], and personal goals. In this course, we hope to achieve that goal through a focus on 'reflection'.

Reflection is a key engineering skill that takes many forms in engineering work. Giving feedback to colleagues or compiling your yearly evaluation are two forms. Another form is debriefs, where teams of engineers meet to discuss what went well or what went poorly on a project. Yet another is troubleshooting - where engineers think back on how something should work and how it is not working properly. Crucially, all types of reflection help engineers learn or understand- either individually or in teams.

Most weeks we will ask you to complete a different reflective activity. As part of those activities, we ask you to not just state an answer but to use examples from prior work, observations, or other experiences. We really love examples and, when you give examples, we encourage you to do more than tell us what happened. You should relate what happened in the example to your own perspective and to something that you learned through the experience. We encourage you to unpack and describe your understanding of concepts and your experiences - not just report them. That being said, *the only wrong answers are ones where you try and find the answer we 'want' or give us something insincere, as opposed to being authentic to yourself.*

Success criteria:

To receive a pass for this assignment, you must:

1. Complete this assignment individually
2. Submit your assignment via Canvas on time
3. Submit an artifact (e.g., something written, drawn, or recorded) that completes the tasks below. It should have a length equivalent to about 500 written words.
4. Feel free to work in the language you are most comfortable, but please submit in English
5. Articulate an understanding of the topics involved in the task using at least one personal example[1]
6. Compare your understanding of the topics involved in the task to your personal example[1]

Action you took:

Your decision to enroll in an undergraduate biomedical engineering program is the result of a long series of individual experiences, actions, and choices. This week we want you to think back on the process that led to a key action: Deciding to join the [INSTITUTION] program.

Task to complete:

For your first 'reflection assignment' we would like you to answer the following four questions:

1. In your perception and experience, what is engineering?
2. With that definition of engineering in mind, what is biomedical engineering?
3. With engineering defined, who is engineering *for*?
4. When is someone being an engineer?

[1] This specification is based on the levels of reflection described in your reading for week two, which drew from Kember, McKay, Sinclair, and Wong (2008)- http://bit.ly/2yPkwJY

2nd assignment (post)
Reflection Assignment: Week 12 - What is engineering redux

General instructions:
One of our course goals is to give each student space to explore biomedical engineering, their plans at [INSTITUTION], and personal goals. In this course, we hope to achieve that goal through a focus on 'reflection'.

Reflection is a key engineering skill that takes many forms in engineering work. Giving feedback to colleagues or compiling your yearly evaluation are two forms. Another form is debriefs, where teams of engineers meet to discuss what went well or what went poorly on a project. Yet another is troubleshooting - where engineers think back on how something should work and how it is not working properly. Crucially, all types of reflection help engineers learn or understand- either individually or in teams.

Most weeks we will ask you to complete a different reflective activity. As part of those activities, we ask you to not just state an answer but to use examples from prior work, observations, or other experiences. We really love examples and, when you give examples, we encourage you to do more than tell us what happened. You should relate what happened in the example to your own perspective and to something that you learned through the experience. We encourage you to unpack and describe your understanding of concepts and your experiences - not just report them. That being said, *the only wrong answers are ones where you try and find the answer we 'want' or give us something insincere, as opposed to being authentic to yourself.*

Success criteria:
To receive a pass for this assignment, you must:
1. Complete this assignment individually
2. Submit your assignment via Canvas
3. Submit an artifact that addresses each part of the task and any special instructions below
4. Articulate a clear and example-driven understanding of the topics or concepts involved in the task[1]
5. Relate your understanding to your personal experience and beliefs to give personal insights[2]

Special instructions for this week:
- You must submit your original reflection in addition to your new reflection
- Your reflection for this week must contain at least two quotes from your first reflection
- You must analyze the quotes from your first reflection to identify at least one thing you agree with and one thing you disagree with from what you wrote at the beginning of the semester.

Action you took:
Maybe you saw this coming or maybe you didn't, but the 2nd to last reflection is basically a repeat of the 1st reflection you wrote. So…finally…Your decision to enroll in an undergraduate biomedical engineering program is the result of a long series of individual experiences, actions, and choices. This week we want you to think back on the process that led to a key action: Deciding to join the [INSTITUION] program.

Task to complete:
Over your first semester, you have (hopefully) gained significant new perspectives on what engineering means to you. We suspect your answers will have increased in nuance, individuality, and in the experiences you have to back them up. We encourage you to go back to your first reflection and would love to see quotes from that reflection in your new reflection as you complete the following three questions:
1. In your perception and experience, what is engineering?
2. With that definition of engineering in mind, what is biomedical engineering?
3. And lastly, how has your answers to those two questions changed over the semester?

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[2] This specification is based on the levels of reflection described in your week two reading, which drew from Kember, McKay, Sinclair, and Wong (2008)- http://bit.ly/2yPkwJY

Kember based codes

Note: the Kember framework is hierarchical and exclusive, only one code is applied per reflection

Table 5 Code definitions for the Kember framework based codes

Level	**Definition**
Habitual Action	No thought is given to applicability or alternatives or when a student responds to an academic task by providing an answer without attempting to reach an understanding of the concept or theory that underpins the topic. Occurs when students search for material on a set topic and place it into an essay without thinking about it, trying to understand it, or forming a view. It is also common to be summarized without a sense of meaning or real understanding of underlying constructs.
Understanding	Student attempts to reach an understanding of a concept or topic. The concepts are understood as theory without being related to personal experiences or real-life applications. In the absence of reflection, though, there will be no examples of how the theory related to a practical situation nor how the concept relates to personal experiences.
Reflection	Takes a concept and considers it in relation to personal experiences. Theory is applied to practical applications. As a concept becomes related to other knowledge and experience personal meaning becomes attached to the concept. In writing, the reflection category goes beyond the understanding category by showing the application of theory. Concepts will be interpreted in relationship to personal experiences. Situations encountered in practice will be considered and successfully discussed in relationship to what has been taught. There will be personal insights that go beyond book theory.
Critical Reflection	Implies undergoing a transformation of perspective. To undergo a change in perspective requires us to recognize and change these presumptions. To undergo critical reflection it is necessary to conduct a critical review of presuppositions from conscious and unconscious prior learning and their consequences. To classify a piece of writing as showing critical reflection, there should be evidence of a change in perspective over a fundamental belief. There is likely to be evidence of the process taking time and displaying the type of steps described.

de Figueiredo based codes

Note: codes are not hierarchical or exclusive - multiple codes can be applied to a given reflection

Table 6 Code definitions for the de Figueiredo framework based codes

Engineer as...	**Definition**
Sociologist	Engineering as part of the social nature of the world and the social complexity of the teams they belong to. The creation of social and economic value and the belief in the satisfaction of end users emerge as central values in this dimension of engineering.
Scientist	Engineering as the application of the natural and exact sciences, stressing the values of logics and rigour. Sees knowledge as produced through analysis and experimentation. Research is the preferred modus operandi of this dimension, where the discovery of first principles is seen as the activity leading to higher recognition.
Designer	Engineering as the art of design that values systems thinking much more than the analytical thinking that characterizes traditional science. Its practice is founded on holistic, contextual, and integrated visions of the world, rather than on partial visions. Typical values of this dimension include exploring alternatives and compromising. In this dimension, which resorts frequently to non-scientific forms of thinking, the key decisions are often based on incomplete knowledge and intuition, as well as on personal and collective experiences.
Doer	Engineering as the art of getting things done, valuing the ability to change the world and overcoming complexity with flexibility and perseverance. It corresponds to the art of the homo faber, in its purest expression, and to the ability to tuck up one’s sleeves and get down to the nitty-gritty. In this dimension, the completed job, which stands before the world, leads to higher recognition.

IRR and positionality

Three of the authors participated in the coding process. We organized the coding process such that 50% of the reflections in the data set were coded twice, independently, by different coders. The remaining reflections were coded by one coder. The coding process is covered in more detail in the methods section. This section reviews the background of each coder, their role in the coding, and describes measures of interrater-reliability (IRR).

The first coder holds a Ph.D. in chemical engineering and a Masters degree in education. She has been worked in engineering education for about 10 years following a career in the pharmaceutical industry. She coded the pre and post reflections for students whose names appear in the first half of the alphabet. The second coder holds a PhD in engineering education and a Masters degree in mechanical engineering. He has worked in engineering education for about 6 years following a career in the semiconductor industry and consulting. He coded the pre and post reflections for students whose names appear in the second half of the alphabet. The third coder holds a PhD in curriculum and instruction, and a Masters degree in college student affairs. She works primarily on student success and first-year program development. She is in her first year working with engineering education. She coded 50% of the pre and post reflections coded by each of the first two coders as a inter rater reliability check..

The table below presents the count of agreements, disagreements, percent agreement, and Cohen's kappa for the 50% of reflections that were coded by two coders. Overall, the agreement was satisfactory but post coding discussion highlighted several areas for clarification as we continue to develop our analytic process. For example, Cohen's Kappa for the Reflection codes was .804 - classified as substantial or excellent (Landis & Koch, 1977) - but we intend to clarify the relationship between students' use of examples and the code levels in future work. Similarly, the values suggest a need to further clarify the definition of the sociologist code which matches with experiences coding. However, all of the codes, except for Doer, have Kappa values in the substantial range. The Doer value falls into the moderate range, with the Kappa value negatively affected by the high prevalence of the code.

Table 7 Interrater reliability calculations for all codes

Code	Agree	Disagree	% Agreement	Kappa
Reflection level	**45**	**11**	**80.4**	**.80**
Habitual Action	1	0	100	
Understanding	5	5	50	
Reflection	30	6	83	
Critical Reflection	9	0	100	
Engineer as...	**170**	**34**	**83**	**.66**
Sociologist	39	12	76	.51
Scientist	44	7	86	.72
Designer	44	7	86	.72
Doer	43	8	84	.46

Qualitative examples of codes

To add some richness to the quantitative results, we wanted to include some qualitative reporting using representative quotes for both of the coding frameworks Tables 8 and 9 below highlight quotes from students that coders noted as exemplifying students' articulation of certain themes or codes. The codes were applied at the reflection (i.e., artifact) level rather than highlighting individual sentences or phrases. The quotes below identify segments of text that the coders identified as key to applying a code to an overall reflection. These quotes were highlighted and labeled during the coding process, selected by one author, and then confirmed by a second.

Table 8 Exemplary student quotes from *reflective level* codes

Reflective level	**Quote**
Habitual action	*According to a quick online search, engineering is 'the branch of science and technology concerned with the design, building, and use of engines, machines, and structures' Indeed this would appear to be a rather comprehensive, though strictly factual, definition.*
Understanding	*Engineering is an approach to problem solving, critical thinking, and data processing utilizing science and math.*
Reflection	*I realize that I've been an engineer long before I knew what the word meant. ...*
Critical Reflection	*Now, at the end of the semester, I still feel that my initial simple definition of engineering...holds true. However, based on what I have learned in this class…, I would add some things to make a more expanded definition.*

Table 9 Exemplary student quotes from the *Engineer as..* codes

Discipline	**Quote**
Sociologist	*This experience completely transformed my perception of what an engineer does, from researchers working passively in a lab to teammates working dynamically to solve a problem.*
Scientist	*[E]ngineering is using problem-solving skills (typically math, science, and technology)*
Designer	*When one thinks critically, analyzes, and solves problems through an integration of multiple perspectives and tools, this is the epitome of what an engineering does.*
Doer	*Engineering is a field pertaining to the design, construction, and application of machines, structures, or chemical compounds for the betterment of society. In simpler terms, making things to solve problems.*